ATLAST: Advanced Technology Large-Aperture Space Telescope

A NASA Astrophysics Strategic Mission Concept Study of the Science Cases & Technology Developments needed to build an AFFORDABLE 8m - 16m UV/Optical Filled-Aperture Space Telescope

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The Imperative for a larger UV/Optical Space Telescope

How did the present Universe come into existence and what is it made of?

- How do galaxies assemble their stars?
- How are baryons distributed in intergalactic space?
- How does the mass of galactic structures increase with time?

Requires velocity and brightness measurements of very faint objects. Requires UV/optical spectra of faint sources in crowded fields.

What are the fundamental components that govern the formation of today's galaxies?

- How do super massive black holes evolve?
- Why is their mass correlated with that of their host galaxies?

Requires UV/optical spectra in central 200 pc of galactic nuclei. Needs high angular resolution & sensitivity.

How does the Solar System work?

- What are the connections between the Solar System's Interplanetary Medium and the Local Interstellar Medium?
- What are the physical processes driving the weather on the outer gas giant planets in the Solar System?

Requires UV spectroscopy of faint sources and high angular resolution UV/optical/NIR narrow band imaging.

What are the conditions for planet formation and the emergence of life?

- What fraction of circumstellar disks form planets?
- Are there detectable biosignatures on exoplanets in the Habitable Zones of their host stars?

Requires high-contrast optical and NIR imaging and spectroscopy of very faint point sources

Is There Life Elsewhere in the Galaxy?

Need to multiply these values by $\eta_{Earth} \times f_B$ to get the number of potentially life-bearing planets detected by a space telescope.
η_{Earth} = fraction of stars with Earth-mass planets in HZ
f_B = fraction of the Earth-mass planets that have detectable biosignatures

Earth-mass planets within these HZ will be very

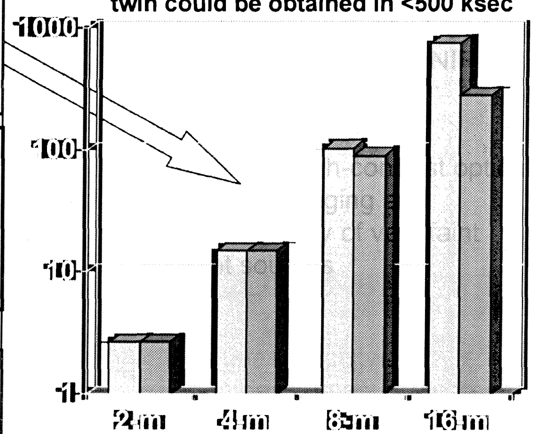
If: $\eta_{Earth} \times f_B \sim 1$ then $D_{Tel} \sim$ 4m
$\eta_{Earth} \times f_B < 1$ then $D_{Tel} \sim$ 8m
$\eta_{Earth} \times f_B << 1$ then $D_{Tel} \sim$ 16m

Number of nearby stars capable of hosting

To maximize the chance for a successful search for life in the solar neighborhood requires a space telescope with an aperture of *at least* 8-meters

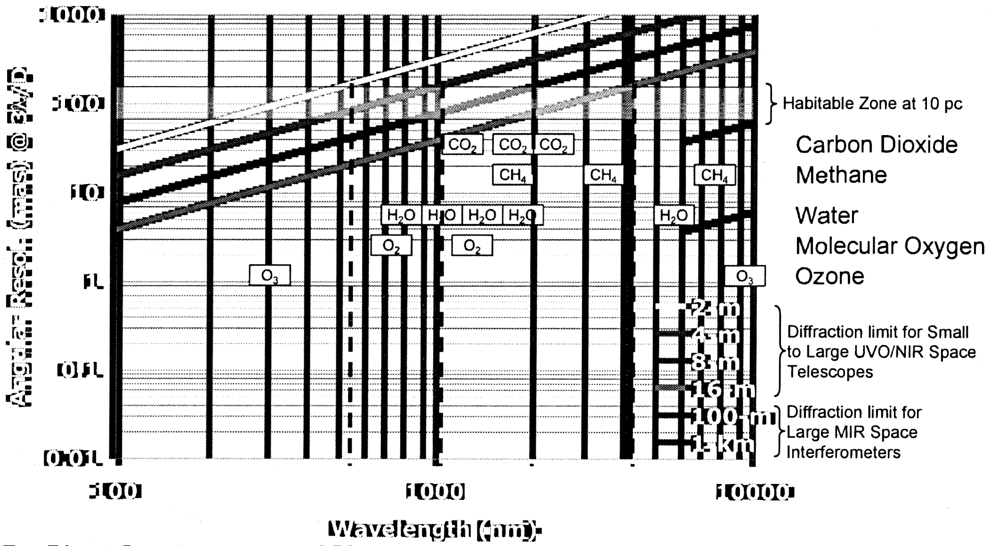
rare. May need to search many systems to find even a handful. Sample size $\propto D^3$

Number of FGK stars for which SNR=10, R=70 spectrum of Earth-twin could be obtained in <500 ksec



Green bars show the number of FGK stars that could be observed 3x each in a 5-year mission without exceeding 20% of total observing time available to community.

Exoplanet Characterization: Are there life-bearing worlds?



- **For Direct Spectroscopy and Photometry: need high angular resolution to resolve the HZ in nearby star systems**
  - **Angular resolution scales as λ/D. Furthermore, technical limitations suggest you will want most of the HZ to lie outside of ~3 λ/D**
  - **1 AU at 10 pc is 100 mas. Solar system HZ: ~0.7 - 1.5 AU.**

Exoplanet Characterization: Are there life-bearing worlds?

- **Earth at 10 pc: ~29.1 AB mag (8.3 nJy)**
- **Earth at 20 pc: ~30.6 AB mag (2.1 nJy)**
- **Sensitivity scales with aperture as D^2 to D^4 depending on exo-zodi level and on method used to suppress starlight.**
- **Need telescope with nJy sensitivity to:**
  - Obtain S/N=10 low resolution (R~100) spectroscopy to identify key habitability and bio-signatures in the range 0.3 - 2.5 microns in <10^6 seconds.
  - Obtain S/N=20 broadband photometry on timescales less than one planetary rotation period (to enable studies of temporal variation on diurnal timescales)

Feature	λ (nm)	Δλ (nm)	SNR	Significance
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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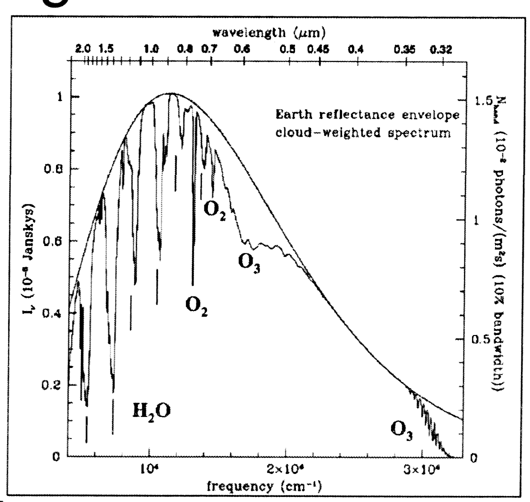
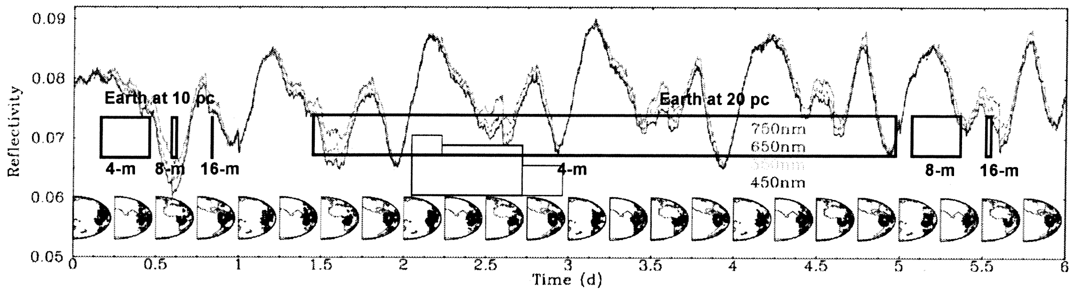


A **S/N=10 spectrum** (R=70) of Earth-like planet orbiting a solar luminosity star at a distance of 20 pc **(V=30.6 AB mag).** The required **exposure time is ~150 hours with an 8-m** space telescope; **~20 hours with a 16-m** space telescope. Habitability and bio-signatures are shown.

Detecting Weather and Surface Features

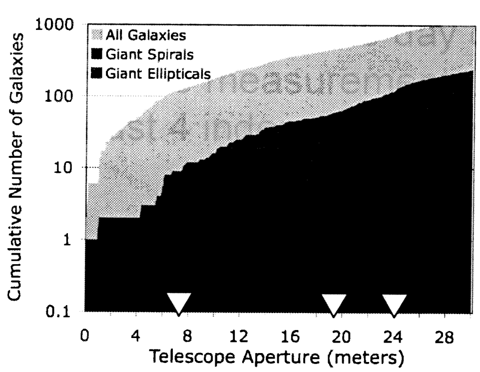
Ford et al. 2003: Model of broadband photometric temporal variability of Earth



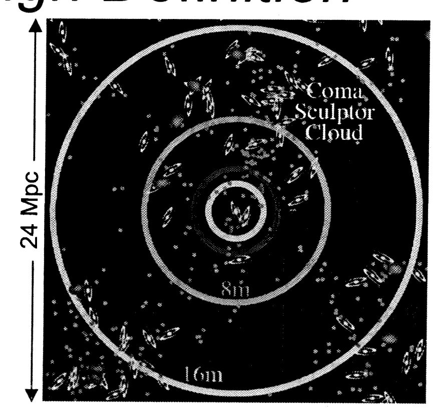
Require S/N ~ 20 (5% photometry) to detect Earth-like temporal variations in reflectivity.
We would need to achieve a single observation at this S/N in < 0.25 day of exposure time in order to enable measurements the variability consisting of at least 4 independent observations per rotation period.

Re-tracing the Star Formation History of Galaxies *in High Definition*

Resolved Stellar Populations: An 8-m to 16-m space telescope will bring about a major revolution in the study of stars, enabling observations of solar-luminosity stars outside the Local Group of galaxies. Observations of solar-luminosity stars on the main sequence are essential to reconstructing the star formation history over the entire lifetime of a galaxy.



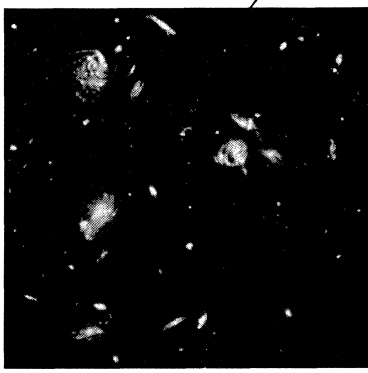
Diffraction limited imaging in V-band (500 nm) of faint point sources over 5 arcmin FOV. Medium to high resolution spectroscopy of faint point sources in UV/Optical passband.

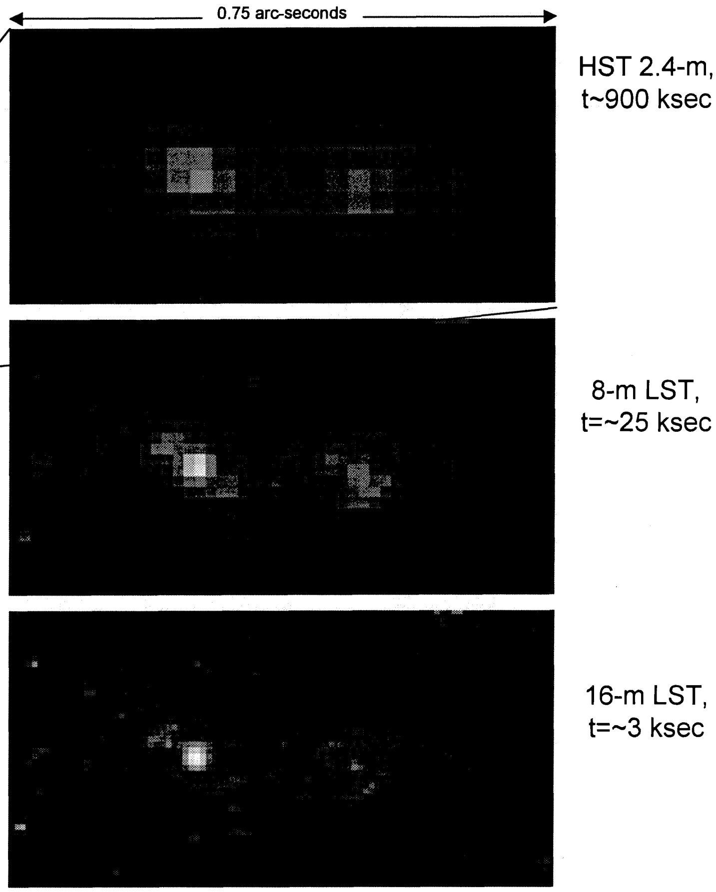


Map of Nearby Galaxies centered on Milky Way Galaxy

We require S/N = 5 photometry of ~thousands of 33 - 35 m_V stars. We also require high-resolution spectroscopic capabilities in the near UV - optical to study the distribution of stellar masses in nearby galaxies.

“Modern” Galaxy Evolution

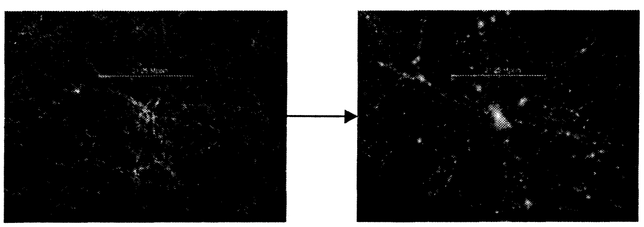




HST Ultra Deep Field

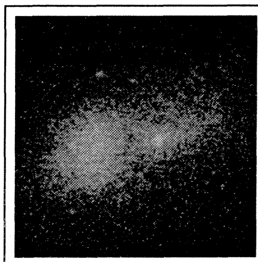
Faint Galaxy:
- 25.1 AB mag (330 nJy) in I-band
- 0.75 arc seconds across
- 2 “peaks” in light distribution
- Morphology unknown

Many astrophysical investigations require the capabilities of a large UVOIR space telescope



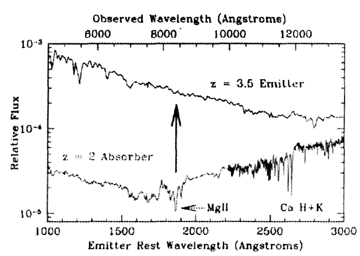
Direct detection & verification of the hierarchical assembly of structure & the processes that govern the interactions between the IGM and galaxies

UV / optical R~1000-2000 absorption spectroscopy of faint galaxies (>26 mag) and QSO's (>22 mag).



Direct measurement of the proper motions of galaxies in the Local Group: direct constraints on the kinematics and distribution of Dark Matter

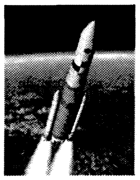
Very stable and well-calibrated imaging (PSF, distortion, pixel scale) on time scales of up to 5 years.



If we want to pursue the compelling scientific issues we imagine today (and the many we cannot imagine), we will need a large UV/optical space telescope as part of our astronomical tool kit. Making it affordable is the strong motivation for a focused technology development program for the coming decade.

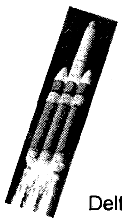
Pathways to a Large UVOIR Space Telescope

If Ares V is built by 2019 …



8-m monolithic mirror Telescope in ~2025 and/or 16-m segmented mirror Telescope in ~2030+

If Ares V is not built …



Delta IV HLV

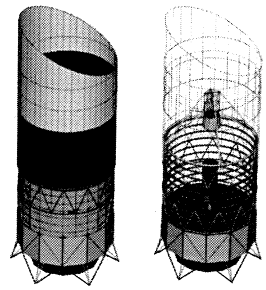
9.2-m segmented mirror Telescope in ~2028 or Elliptical (light-weight) monolithic mirror Telescope in ~2028

Ares V payload to L2 = 65 mT, Delta IV HLV payload to L2 = 16 mT

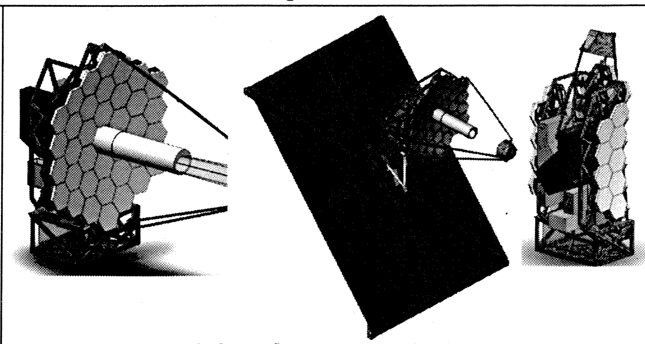
Studying two architectures: 8-m monolithic and (9.2-m, 16.8-m) segmented telescope

- Monolithic Primary
  - On and off-axis secondary mirror concepts being investigated.
  - Off-axis concept optimal for exoplanet observations with internal coronagraph. But adds complexity to construction and WFS&C.
  - Uses existing ground-based mirror materials. This is enabled by large lift capacity of Ares V cargo launch vehicle (~65 mT to L2).
  - Massive mirror (~20 mT) has ~7 nm rms surface. Total observatory ~50 mT.
- Segmented Primary
  - Only studying designs with an on-axis secondary.
  - Requires use of lightweight mirror materials & fabrication
  - 9-m observatory has total mass ~16mT; 16-m observatory has total mass ~35 mT. Both are within capacity of Ares V.
  - 9-m observatory can fly in advanced ELV. Does not require Ares V.
  - Both 9-m and 16-m require active WFS&C systems.

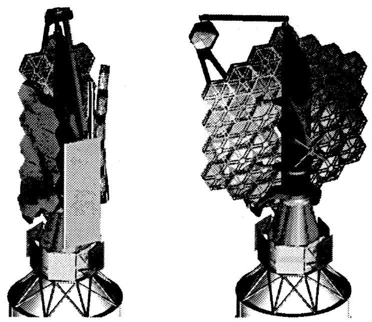
ATLAST Concepts



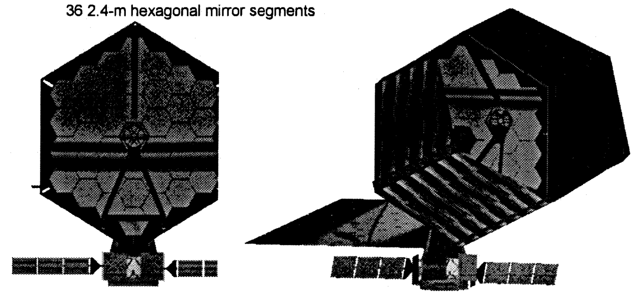
8-m Monolithic Primary
(shown with on-axis SM configuration)



9.2-m Segmented Telescope
36 1.3-m hexagonal mirror segments

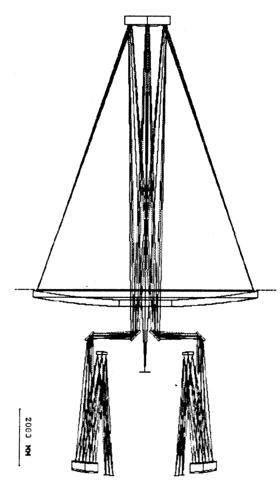


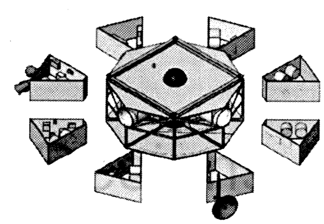
16.8-m Segmented Telescope
36 2.4-m hexagonal mirror segments



Common Features for all Designs

- Diffraction limited @ 500 nm
- Designed for SE-L2 environment
- Non-cryogenic OTA at ~290° K
- Heaters stabilize PM temperature to ± 0.1° K
- OTA provides two simultaneously available foci - narrow FOV Cassegrain (2 bounce) for Exoplanet & UV instruments and wide FOV TMA channel for Gigapixel imager and MOS
- Designed to permit (but not require) on-orbit instrument replacement and propellant replenishment





Technology Development Needed in Coming Decade Relevant to "Life Detection"

- 8m Monolithic Telescope
  - High-contrast (10^{-10}) starlight suppression:
    - Internal Coronagraph
    - External Occulter
  - Active observatory wavefront control system
  - Ultra-low or zero noise photon counting detectors
  - Ares V Cargo Launch Vehicle (enabling technology for full circular aperture and cost control => less complexity)
- 10m to 16m Segmented Aperture Telescope
  - High-contrast (10^{-10}) starlight suppression:
    - Vis. Nulling Coronagraph
    - External Occulter
  - Light-weight mirror materials and manufacturing (<15 kg/m^2)
  - Active observatory wavefront control system
  - Ultra-low or zero noise photon counting detectors
  - Ares V Cargo Launch Vehicle (for 16m).

Technology Development Needed for ATLAST

Technology Development for:	8-m	9.2-m	16.8-m
• Starlight Suppression Systems:			
Hi-contrast Coronagraph -or-	○	○	○
External Occulter	○	○	○
• Gigapixel Detector Arrays	○	○	○
Photon-counting Detectors	○	○	○
High Efficiency Dichroics	○	○	○
High Efficiency UV coatings	○	○	○
• Optical Telescope Assembly			
Advanced WF Sensing & Control		○	○
Fully Active Optics		○	○
Lightweight Mirror Materials		○	○
Lightweight Mirror Fabrication		○	○
Milli-arcsecond pointing control	○	○	○
Flight qualif. of monolithic mirror	Requires engineering, but no new tech.		
• Systems Modeling & Verification	○	○	○
• Autonomous Rendezvous & Docking	○	○	○

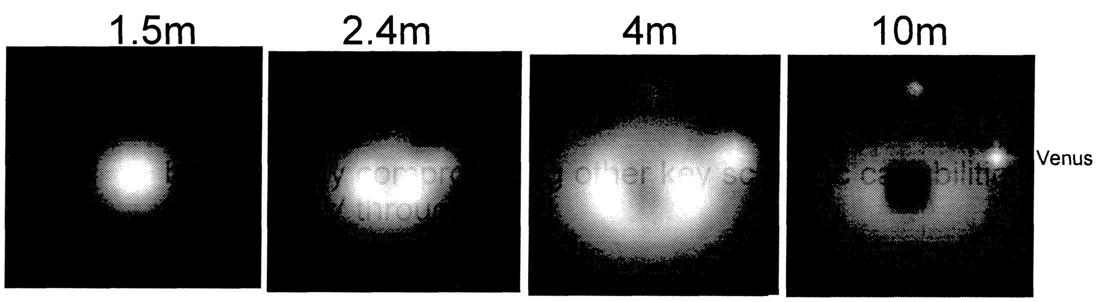
○ TRL6 or higher ○ TRL4 or higher ○ TRL3 or lower

Starlight Suppression

- Characterizing terrestrial-like exoplanets (<10 M_{earth}) is a prime ATLAST scientific objective.
- Challenge: how do we enable a compelling terrestrial exoplanet characterization program without:
  a) making the optical performance requirements technically unachievable for a viable cost (learn from TPF-C) and
  b) seriously compromising other key scientific capabilities (e.g., UV throughput).

Starlight Suppression Options: External Occulter (Starshade)

Credit: Web Cash 2008



Above: a simulation of our solar system at a distance of 10 pc observed with an external occulter and a telescope with the indicated aperture size. The two planets are Earth and Venus. The challenges of deploying the starshade, and maneuvering it into position, also increase with increasing telescope aperture.

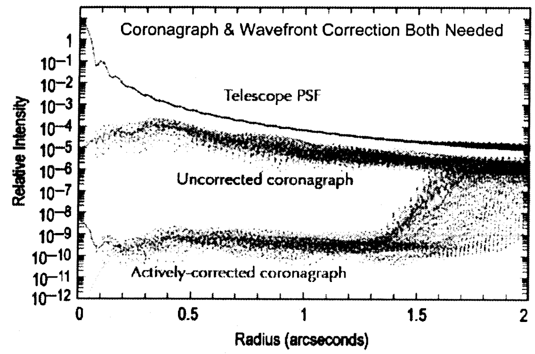
Starshade Parameters:	8-10m telescope: 80m shade @ ~165,000 km
	16m telescope: 90m shade @ ~185,000 km

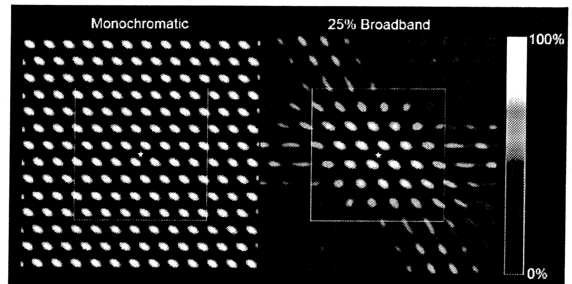
Characterizing Exoplanets: Via the use of an external occulter, one can suppress the light of the central star, enabling the detection of any orbiting exoplanets. Detecting and characterizing these, however, becomes progressively easier with increasing telescope aperture.

Starlight Suppression Options: Internal Coronagraphs

- JPL's High-Contrast Imaging (HCI) Test-Bed has demonstrated sustained contrast levels of < 10^{-9} using internal, actively corrected coronagraph.
- Segmented optics introduce additional diffracted light. Visible Nulling Coronagraph (VNC) can, in principle, work with segmented telescope to achieve 10^{-10} contrast. VNC chosen as starlight suppression method for TMT Planet finding imager as well as for EPIC and DAVINCI mission concepts.

1.8m telescope, contrast 1E-9 with IWA of 0.25 arcsec. W. Traub et al.

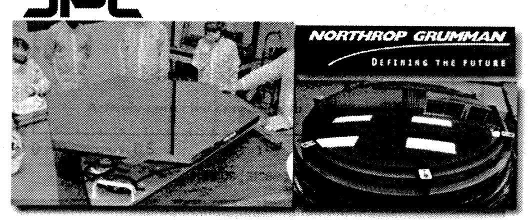




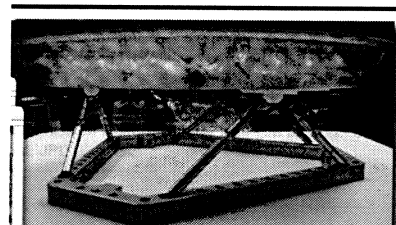
VNC Sky Transmission Pattern with 64 x 64 DM at 0.68 - 0.88 microns. Credit: J. Krist, JPL

Lightweight Mirror Technology

- There are at least two potentially viable lightweight mirror technologies:
  - Nanolaminate Actuated Hybrid Mirror (AHM)
  - Corrugated Glass Mirror
- Both materials already demonstrated to achieve 8 - 12 kg/m^2 areal densities; lower values possible.
- 0.6 - 1.2m class mirror segments exist. Overall TRL ~ 4.
- Need to develop 1.3 - 2.4 meter class, space-qualified segment production for ATLAST

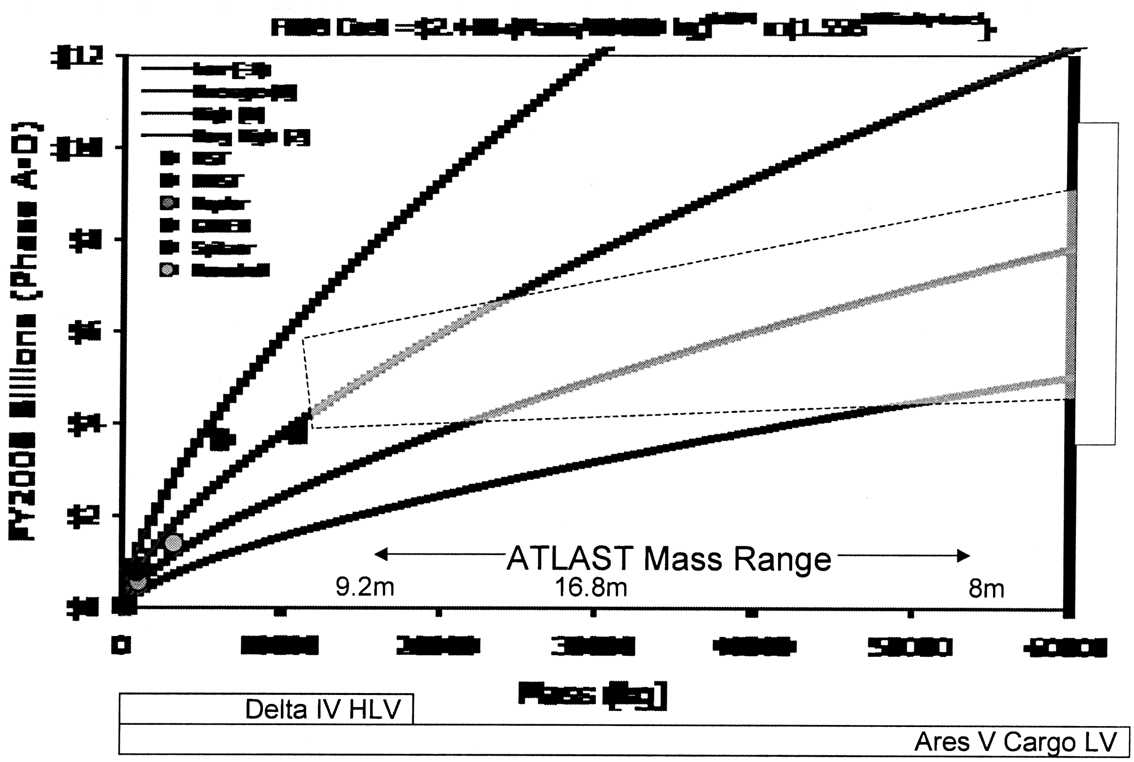


Nanolaminate materials are multi-layer metallic foils grown by sputter deposition with atomic-scale control. Current material systems have low thermal expansion and low residual thermal stress to match AHM SiC substrates thermal expansion. Final figure achieved by depositing onto inversely shaped mandrel.



Corrugated mirror made by pressing thin glass sheets into cores, then fused together.
Front sheet reinforced every 5mm (no quilting); High stiffness; Slumped to near final figure.

Key Objective of Technology Development: Break the Cost Curve



Large UVOIR telescopes are required for a broad range of astrophysical research

- Star formation & evolution; resolved stellar populations
- Galaxy formation & evolution; supermassive black hole evolution
- Formation of structure in the universe; dark matter kinematics
- Origin and nature of objects in the outer solar system
- Characterization of Terrestrial-sized Exoplanets in HZ of solar type stars.

A “life finder” telescope will clearly be a multi-billion dollar facility - and support by a broad community will be needed if it is to be built.